Power Grid Monitoring and Alerting System

Adapting *The Morning Report* technology
for monitoring
the Electrical Power Grid

***The Morning Report* was originally developed**
as part of NASA's Aviation Safety Program.

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Overview of FY06 work and Vision for a Power Grid Monitoring and Alerting System

- Overview of Data Analysis Approach developed for the NASA Aviation Safety Program

- Review of results of analysis of PMU data for Western Grid

- Vision

Overview of Data Analysis Approach developed for the NASA Aviation Safety Program

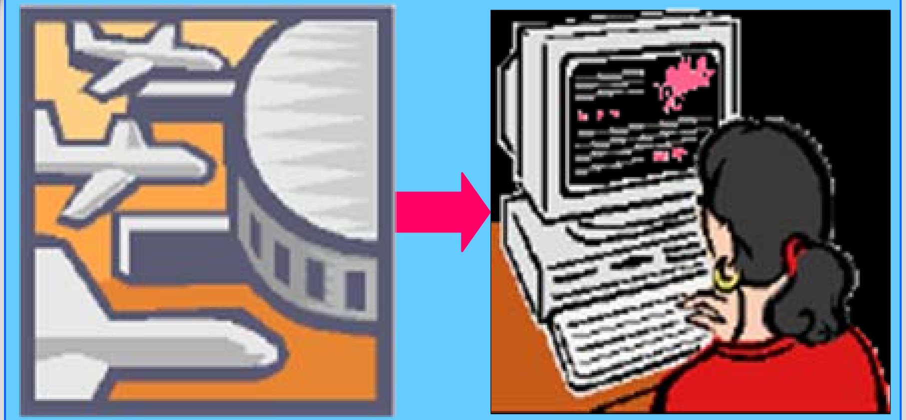
How to do it?
The key elements of the approach

- Aviation Safety Program uses:
  - On-board instrumentation to record hundreds of variables that monitor the aircraft throughout every flight.
  - Sophisticated statistical analysis programmed into a workstation that analyzes the data to find:
    - Typical patterns, that characterize ~99% of the flights
    - Atypical events, that are worthy of individual inspection
  - User-friendly software enables the aviation user to rapidly and effectively drill into the gigabytes of data to find the insight needed to:
    - Understand safety issues and formulate corrective plans if appropriate
    - Monitor typical patterns for trends
  - Aviation Experts inspired by new insight proactively identify and correct safety issues affecting aviation safety

- Electrical Power Grid
  - Instrumented system operation: PMU systems
  - Adapt statistical analysis: Proof-of-concept in work
  - User-friendly software: On-hold
  - Expert review of results: Yuri Makarov

The Morning Report can be described in 12 Basic Steps

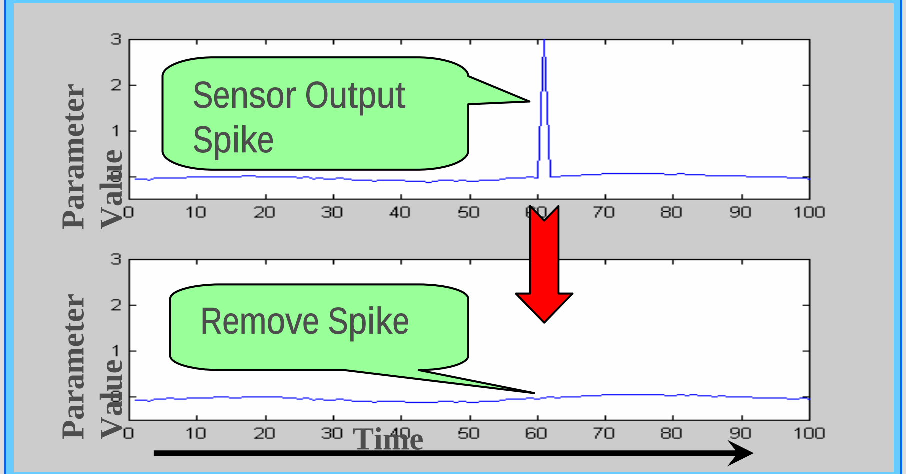
Step 1: Download Data



- Download daily or weekly
- From tapes, disks, or solid state devices
- Use commercially available playback software
- Insert data into commercially vended database

• PMU data continuously recorded
• > 400 variables from > 30 locations
• Data could be:
  • Live / real time
  • From archives

Step 2: Check the Data Quality



- Apply knowledge-based filters
- Identify “bad” data
- Remove the “bad” data
- Inform user of QA problems

Limited data checks to remove dramatically bad data.

Step 3:
Conduct Pre-defined Exceedance Checks

- Airline experts define specific data comparisons to be made at specific routine events
  - Are the gear down while altitude is above 18,000 ft?
  - Are the flaps extended while airspeed is greater than 300 knots?
  - Etc.

Time (secs)	Param 1	Param 2	. . .	Param P	Routine Events
1	103.40	1		277.40	Start Takeoff
2	103.70	1		266.30	
…	…	…	…	…	
126	104.49	1		267.31	
127	104.98	1		268.19	
[illegible]	[illegible]	[illegible]		[illegible]	
129	105.45	0		269.12	Gear Up
[illegible]	[illegible]	[illegible]		[illegible]	
131	106.39	0		269.78	
…	…	…	…	…	
4021	106.82	0		270.71	
4022	107.33	0		270.78	
4023	107.89	0		270.85	10000 ft AFE
4024	108.40	0		271.14	
4025	108.53	0		271.53	
4026	109.38	0		272.03	
. . .	…	…	…	…	
N	110.68	0		273.70	Touchdown

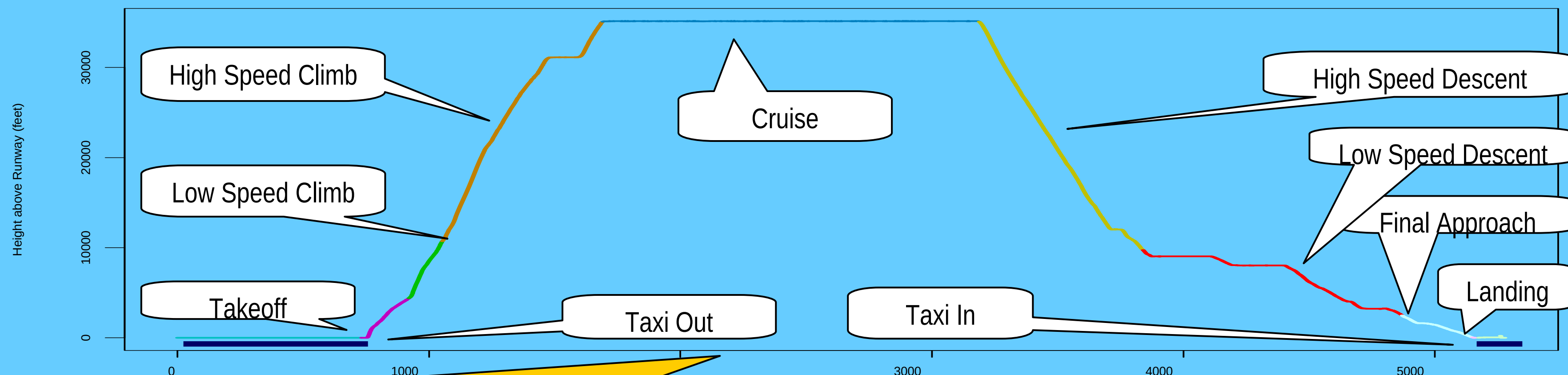
This requires that we <u>envision</u> the potential problems before they occur.

Power Grid Domain Experts could create Boolean Expressions for automatic monitoring.
This effort is not part of the Proof-of-Concept investigation.

Step 4:
Structure the Data

- Data are parsed into flight segments
- Flight Segments based on Event Markers, e.g.
  - Gear-up
  - Cross outer-marker
  - Descent through 1000 ft AFE
- Customizable to each air carrier phase definitions

Time (secs)	Param 1	Param 2	. . .	Param P	Event Marker	ACR Phase
151						
152	103.40	1		277.40	Rotate	Takeoff
153	103.70	1		103.70		
...	...	...	...	...		
335	105.13	1		105.13		
336	105.45	0		105.45	Gear Up	
337	105.73	0		105.73		
...	...	...	...	...		climb
1225	106.82	0		106.82		
1226	107.89	0		107.89	10000 ft AFE	
1227	108.10	0		108.07		
...	...	...	...	...		
3236	108.51	0		109.04		
3237	109.33	0		109.12	Max Altitude	Cruise
3238	110.25	0		109.74		
...	...	...	...	...		
6259	109.04	0		108.60		
6260	109.85	0		109.57	10000 ft AFE	
6261	109.87	0		110.39		
...	...	...	...	...		Approach
6673	110.70	0		110.53		
6674	111.19	0		110.68	Gear Down	
6675	111.90	1		111.29		
...	...	...	...	...		
7786	112.13	1		112.10		Landing
7787	112.91	1		112.43	Touchdown	
7788	113.63	1		112.90		



Data maybe partitioned into “60 second” observations.
Observations may be grouped for comparison as function of Time-of-Day and Day-of-Week.

Step 5:
Create Derived Parameters to Capture Physics Based Insights

- Aircraft heading with respect to runway
- Aircraft location with respect to runway
- Derived Energy Parameters
  - Total energy
  - Kinetic energy
- Others

Sin/Cos of Phase Angle
Deltas among various Bus locations
Physics based / Insightful Variables: TBD

Step 6:
Calculate Preliminary Flight Parameter Signatures

- Continuous Variable
  - Air speed, roll, altitude, vibration, etc.
- Discrete Variables
  - Gear position, autopilot mode, reversers status, etc.
- Data Compression Signature

May use similar signature with multiple temporal focuses:
X seconds / Y minutes

Step 7:
Store the Signatures into the Database

For Proof-of-Concept, use R&D convenient storage.

Step 8: Select the Data

- Select a subset of data:
  - Aircraft type
  - Airports
  - Flight Phase
  - Time Frames
  - Other Parameters

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May look at WECC as whole.
May look at subset (e.g.; Olympic Peninsula)

Step 9: Transform the Signatures

- Multivariate mathematical statistical techniques used enable:
  - Time series analysis
  - Characterization independent of phase duration
  - Flight mode transitions
  - Quantification captures values, trends, & noise

Time (secs)	Param 1	Param 2	. . .	Param P	Event Marker	ACR Phase
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May combine adjacent time periods for analysis
(e.g.; 8-9am 9-10am, … 3-4pm maybe combined)

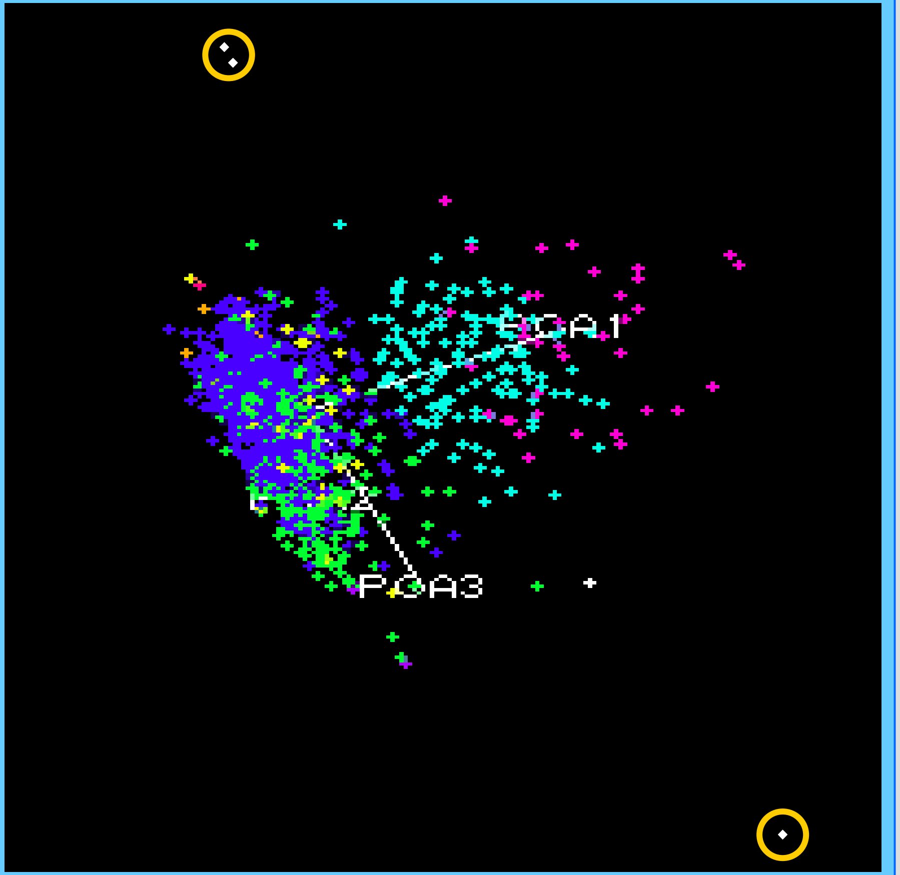
Step 10:
Cluster the Transformed Signatures

- Use several alternative clustering methods
  - Then, generate a consensus
- Typical patterns
  - Clusters of similar flights
  - Summarized in plain English via Storymeister
- Atypical flights
  - Singletons, clusters of one or two
  - Summarized in plain English via Rationale
- Performed for each user-defined and selected flight phase

• Each dot represents a observation.

• Dots are mapped to patterns with similar characteristics.

• Some observations may be mapped to very small clusters.



Step 11: Find the Atypical Flights

- Atypical flights are defined to be
  - Singletons
  - Very small clusters (atypical clusters)
- Differs from classic exceedance analysis
  - Which look for parameter values outside of <u>pre-defined</u> ranges within a flight phase
- Can be the impetus for further investigation
  - By operationally knowledgeable persons

• Atypical behavior of the Power Grid will be identified by the methodology.

• Domain Experts will assess the significance of the atypical behavior.

• If it represents insightful finding:

EUREKA !!!!

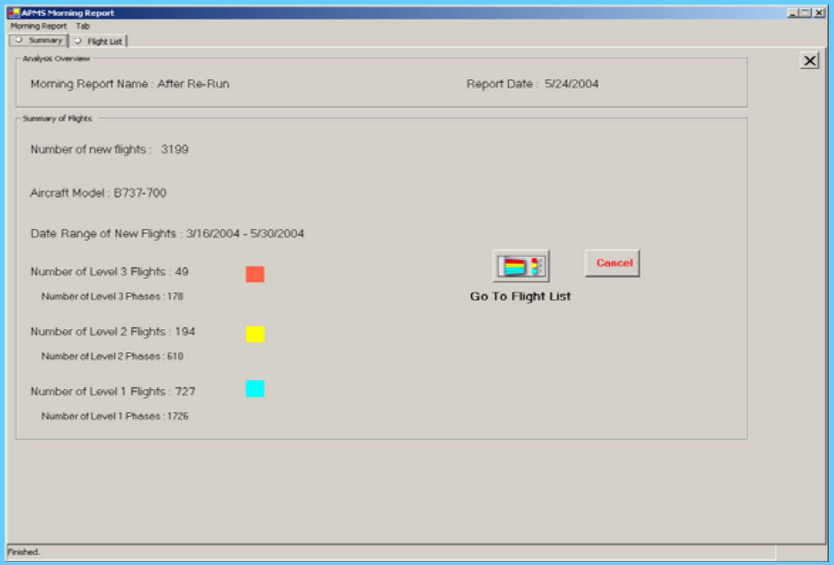
Finds the <u>unenvisioned.</u>

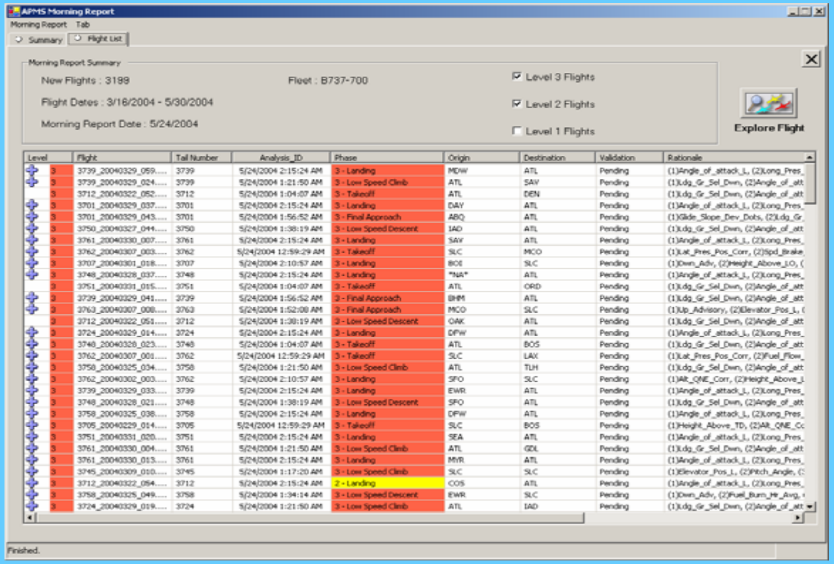
End-users don't have to know what they are looking for !!

The analysis finds atypical events never dreamt of !!

Step 12:
Present the Findings

- Data processing occurs over night
- Morning report is ready by 7am every morning.
- Identifies most atypical flights
  - Excludes flights previously reviewed and dispositioned
  - Enables drill down to flight details
  - Allows capture images in Microsoft PowerPoint files for communication ease.

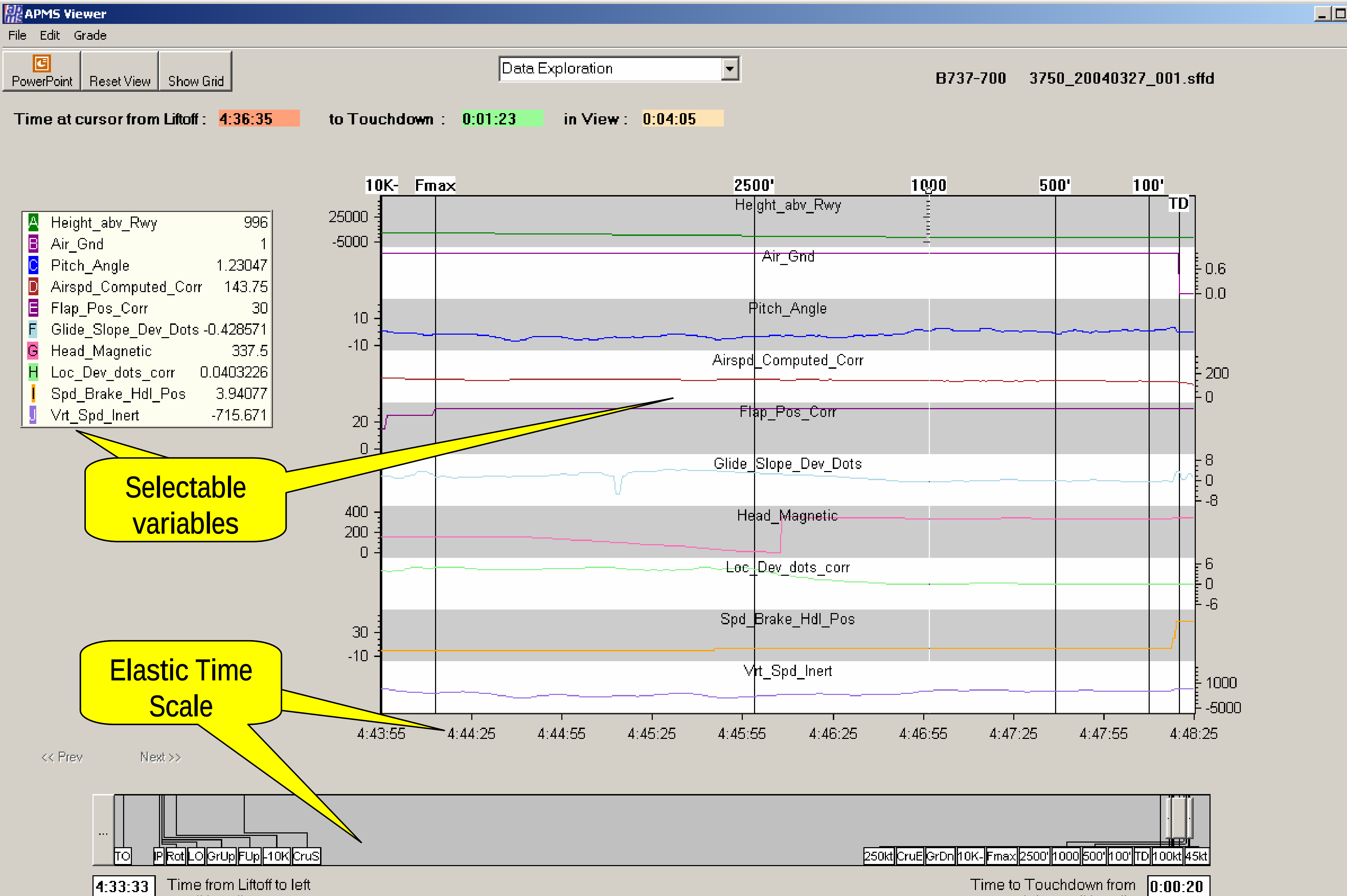




- Nature of the displays are TBD.
- Frequency of the displays are TBD.
- Display focuses on atypical events.

This may evolve to *The Minute Report.*

Drill-down Example



Summary of Approach Characteristics

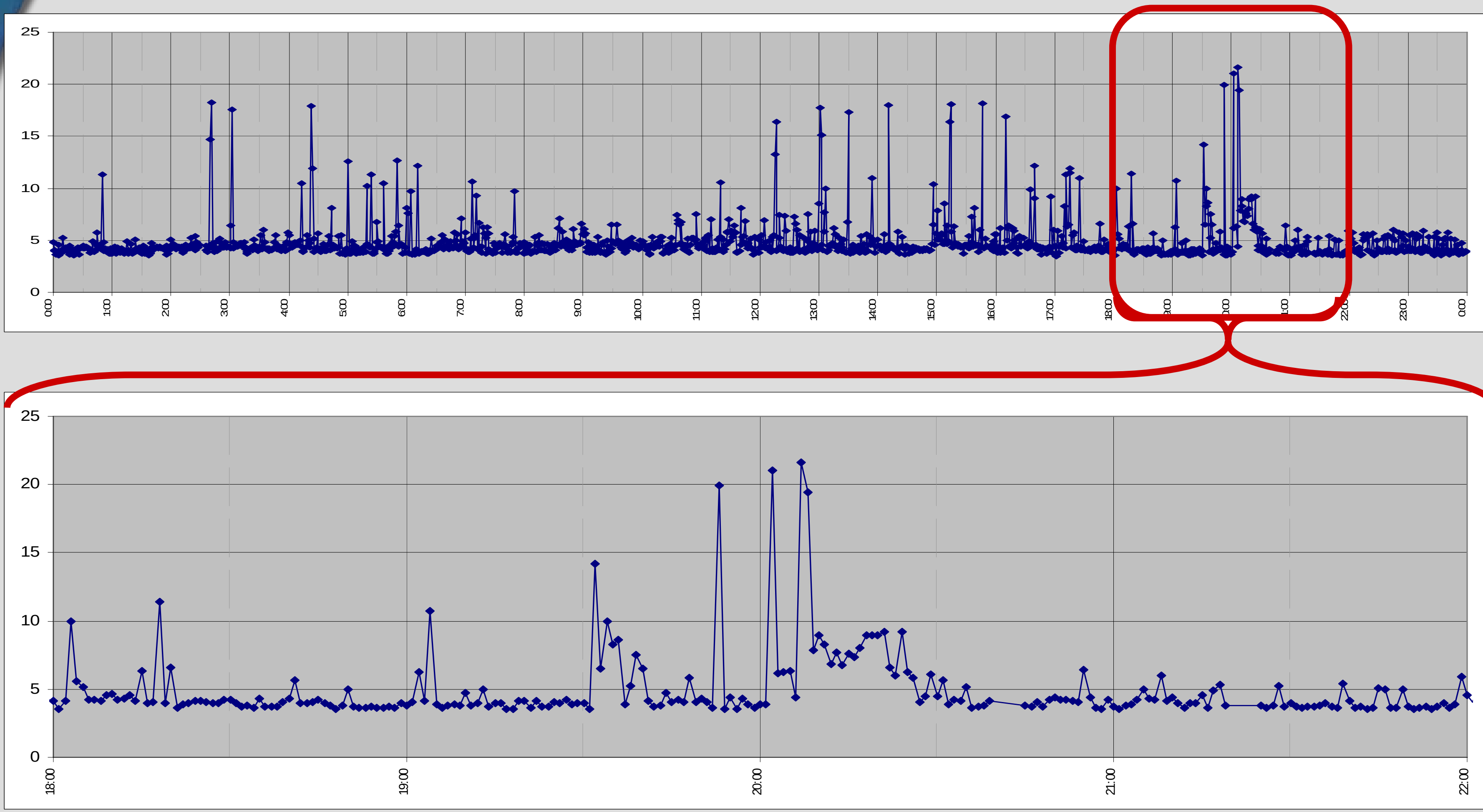
- NASA invested > $6 million over 10 years to move beyond traditional Statistical Quality Control approaches.
  - This technology is multivariate data-driven, with an option to incorporate physics-based elements.
- This technology has won multiple prestigious awards:
  - R&D 100 award, one of the best 100 inventions world-wide, 2005
  - R&D 100 Editor's Choice Award, Invention with the Greatest Impact on Safety
  - Federal Laboratory Consortium award for transfer of technology developed at a federal lab to the community, 2007
  - American Statistics Association, Best Statistical Application 2006
- For more info and a 5-minute overview video:
  - http://www.pnl.gov/statistics/RandD100.htm

Review of results of analysis of PMU data for Western Grid

- 9/12/05
- 38 substations in Western Grid
- Voltage, Phase Angle, Frequency at 30 Hz

Atypicality Index for 1 day

Data is covered by NDA. Protect data. Proprietary data

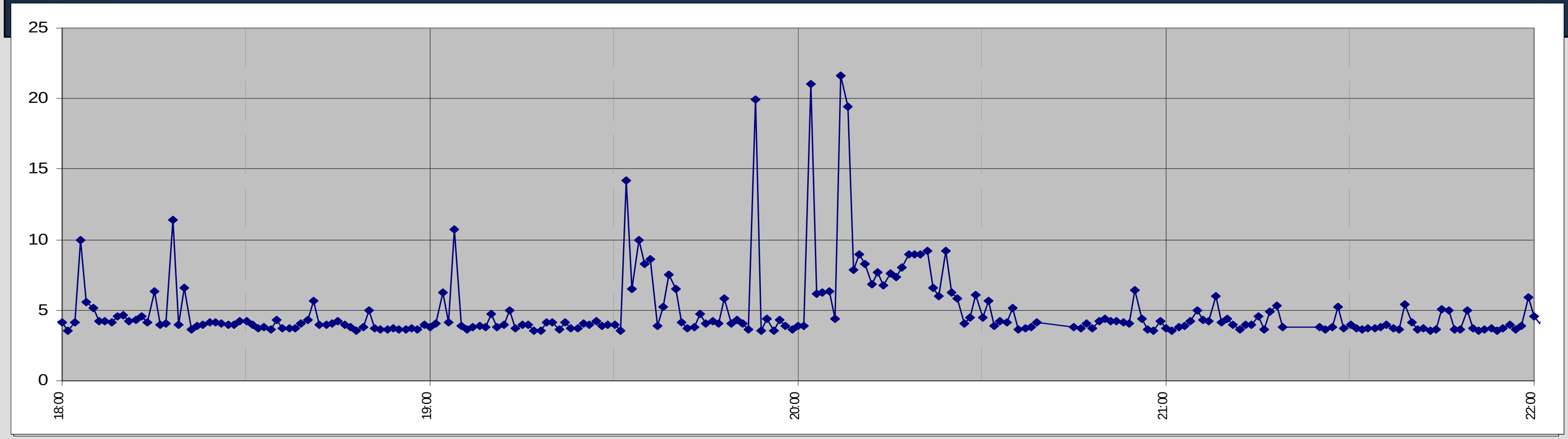


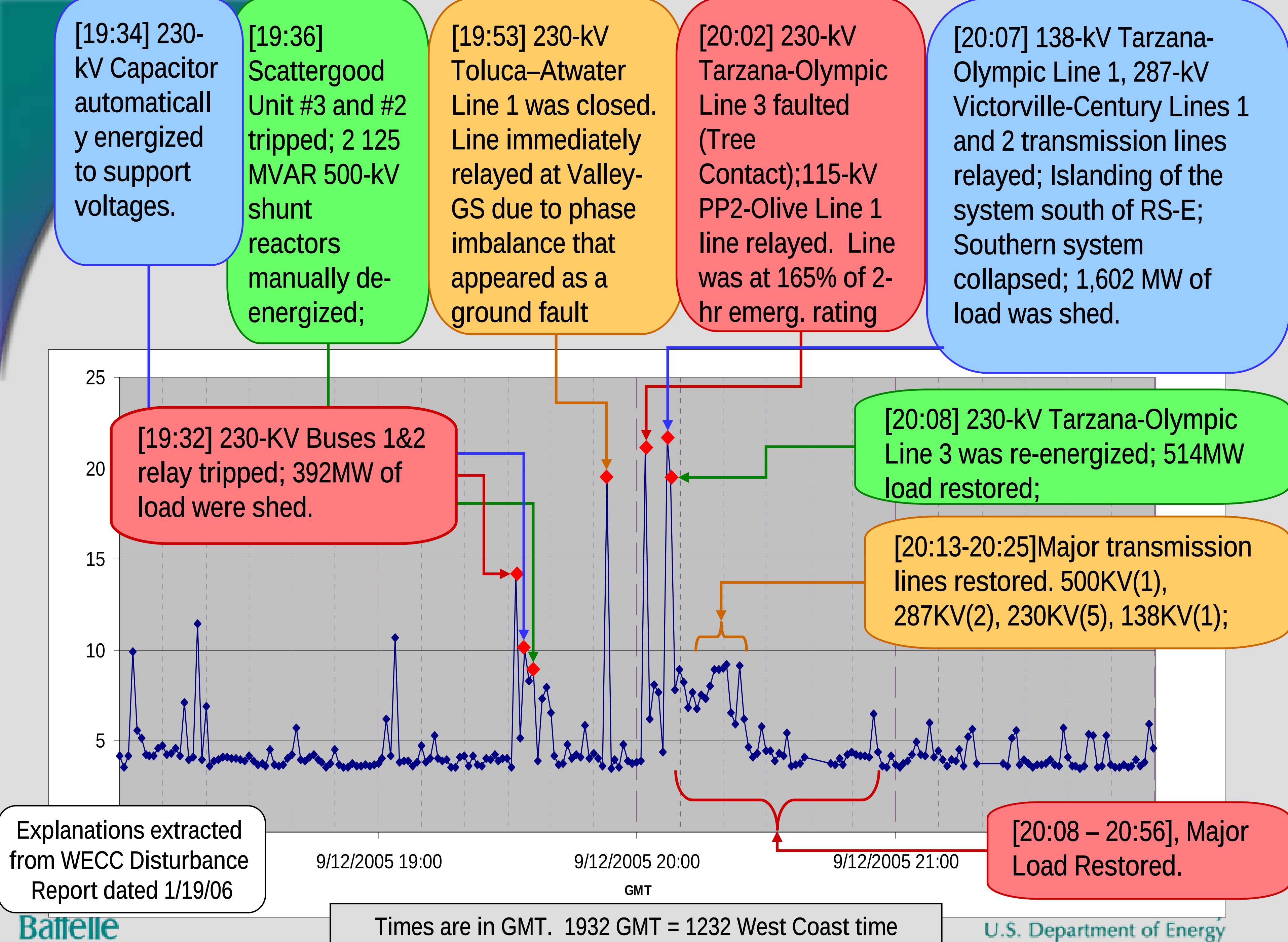
Atypicality Index for 1 day

Data is covered by NDA Protect data Proprietary data

Rationale identifies variables that contribute significantly to the Atypicality Index
And presents summary in plain English; e.g.:

Variable W is very low.
Variable X is low.
Variable y is high.
Variable Z is very high.

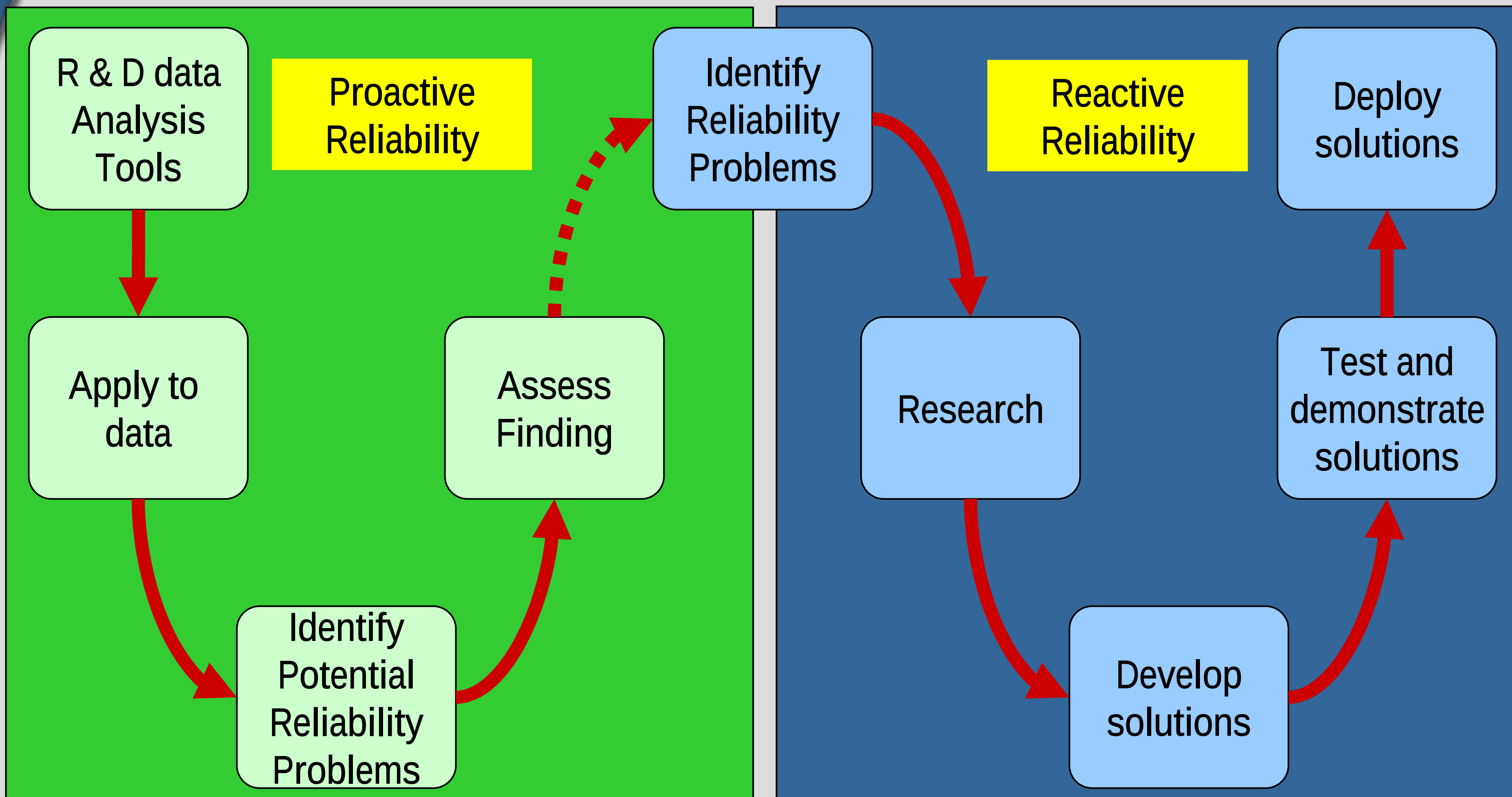




[19:34] 230-kV Capacitor automatically energized to support voltages.
[19:36] Scattergood Unit #3 and #2 tripped; 2 125 MVAR 500-kV shunt reactors manually de-energized;
[19:53] 230-kV Toluca–Atwater Line 1 was closed. Line immediately relayed at Valley-GS due to phase imbalance that appeared as a ground fault
[20:02] 230-kV Tarzana-Olympic Line 3 faulted (Tree Contact);115-kV PP2-Olive Line 1 line relayed. Line was at 165% of 2-hr emerg. rating
[20:07] 138-kV Tarzana-Olympic Line 1, 287-kV Victorville-Century Lines 1 and 2 transmission lines relayed; Islanding of the system south of RS-E; Southern system collapsed; 1,602 MW of load was shed.
[19:32] 230-KV Buses 1&2 relay tripped; 392MW of load were shed.
[20:08] 230-kV Tarzana-Olympic Line 3 was re-energized; 514MW load restored;
[20:13-20:25]Major transmission lines restored. 500KV(1), 287KV(2), 230KV(5), 138KV(1);
[20:08 – 20:56], Major Load Restored.
25
20
15
10
5
9/12/2005 19:00
9/12/2005 20:00
9/12/2005 21:00
GMT
Explanations extracted from WECC Disturbance Report dated 1/19/06
Times are in GMT. 1932 GMT = 1232 West Coast time

Vision

Optimum Reliability comes from using both Proactive and Reactive Efforts



Goals

- Off-line Support (Morning Report):
  - Automated identification, characterization and localization of atypical events
  - Reconstruction of sequence of significant events
  - Identification of typical patterns and sequence of transitions amongst typical patterns
  - Identification of typical patterns exhibited as a result of intentional actions (e.g., grid re-configuration)

- Near-Real-Time automated operational support:
  - Alert for abnormal events w/ characteristics & locations
  - Distinguish
    - expected and benign
    - problem indicators
  - Communication and coordination amongst grid operators

- Forecasting
  - Pre-cursor identification of atypical events
  - Long-term and cyclic pattern detection
  - Expected Worst Case and uncertainty bounds for upcoming season and out-years
  - "What if" studies

- Misc.
  - Extend to SCADA data and other information sources
  - Enhance with other analytical tools – existing and in R&D
  - Training aide
  - Communication and coordination across EI

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Questions and Natural Next Steps

- ?